What are stainless steels?

Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 04

What are the stainless steels?
Videos

100 Years of Stainless Steel
http://worldstainless.org/publications/videos

Alloyed for Lasting Value
http://worldstainless.org/publications/videos

Self-repairing for Lasting Value
http://worldstainless.org/publications/videos
Stainless steels are Iron-base alloys containing at least 10.5% chromium.

Increasing Cr content increases the effectiveness of the passive film... but there are other important factors that influence the corrosion resistance (see Chapter 5).
What are stainless steels?

Stainless steels

- **Martensitic**
  - Plain chromium stainless steels that can be strengthened by heat treatment.
  - 10-17% Cr, 0.1-1.2% C, 0-4% Ni
  - Super Ferrites
  - Conventional Ferrites
  - Utility Ferrites

- **Ferritic**
  - Plain chromium stainless steels, but with low carbon levels, therefore cannot be strengthened by heat treatment.
  - Generally considered to have poor weldability with the exception of the utility grades

- **Duplex**
  - Mixed ferrite-austenitic crystal structure (duplex)
  - Higher levels of Cr and lower levels of Ni as compared to the austenitic grades. Contain nitrogen.
  - High strength and good corrosion resistance.
  - Weldable

- **Austenitic**
  - Ni containing stainless steels. Most common grades which accounts for 70% of all stainless steel usage.
  - Excellent corrosion resistance and associated secondary properties. Suitable for a wide range of applications.

**Magnetic**
- Martensitic structure
- Add carbon

**Non-magnetic**
- Ferritic structure
- Add nickel
- Duplex structure
- Add more nickel
- Austenitic structure

Plain chromium (Cr) + Nickel (Ni) addition

Iron (Fe)
Cr-Ni Grades (Austenitics)\(^4\)

**Sub-groups:**

<table>
<thead>
<tr>
<th>Sub-group</th>
<th>Alloy Composition</th>
<th>Typical EN/ASTM Number</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Fe: Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr-Ni</td>
<td>Typically EN 1.4301/AISI 304</td>
<td>Cr: 18 Ni: 9</td>
<td>Fe: Balance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr-Ni-Mo</td>
<td>Typically EN 1.4401/AISI 316</td>
<td>Cr: 18 Ni 10 Mo: 2.5</td>
<td>Fe: Balance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Common Properties:**

- Very good corrosion resistance, increases with alloy content
- ... but can be susceptible to SCC in hot chloride environment (e.g. swimming pools)

- High ductility and impact resistance at all (including very low) temperatures
- Strength can be increased by cold working (but not by heat treatment)
- Very good fire resistance

- Very good cold and hot forming properties (ductility, elongation)
- Easy to weld (TIG, MIG)

The best known and still the most used today
Cr-Mn Grades (Austenitics with Manganese)\textsuperscript{5}

Typical grade:

- Cr-Mn-Ni-N Typically EN 1.4372/AISI 201 Cr: 17 Mn: 7 Ni: 4 N:0.15 Fe: Balance

Common Properties:

- Lesser corrosion resistance
- ... but far more susceptible to SCC and to pitting, particularly at low Ni and Cr levels
- Higher strength
- Poor cold forming properties due to high work-hardening
- Poor machinability
- More difficult to weld
- Cost less than Cr-Ni Austenitics ... but more than Cr ferritics

Used mostly in India and China
Cr Grades (Ferritics)\(^6\)

### Sub-groups:

<table>
<thead>
<tr>
<th>Sub-group</th>
<th>Cr Grade</th>
<th>Typical Composition</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>Cr 17 Fe: Balance</td>
<td>Insensitive to Stress Corrosion Cracking</td>
<td>Strength can be somewhat increased by cold working (but not by heat treatment)</td>
</tr>
<tr>
<td>Cr-Mo</td>
<td>Cr 18 Mo 2 Ti+Ni 0.4 Fe: Balance</td>
<td>Good ductility (lower than austenitic grades, though)</td>
<td>Very good cold forming properties: (less springback, lower tool wear but lower elongation requires a different deep drawing process compared to austenitics)</td>
</tr>
</tbody>
</table>

**Common Properties:**

- Insensitive to Stress Corrosion Cracking
- Good ductility (lower than austenitic grades, though)
- Not suitable for use at very low temperatures
- Strength can be somewhat increased by cold working (but not by heat treatment)
- Very good cold forming properties: (less springback, lower tool wear but lower elongation requires a different deep drawing process compared to austenitics)
- Stabilized grades (i.e. with Nb and/or Ti) are easy to weld (TIG, MIG)

Colour code:  ▪ Corrosion resistance ▪ Mechanical properties ▪ Fabrication

*Offer an optimum performance/cost for many applications and are increasingly used*
Cr Grades (Martensitics)\(^7\)

<table>
<thead>
<tr>
<th>Sub-groups:</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-Cr</td>
<td>Typically EN1.4021/AISI 420 Cr: 13 C:0.2 Fe: Balance</td>
</tr>
<tr>
<td>C-Cr-Ni</td>
<td>Typically EN1.4057/AISI 431 Cr: 16 Ni: 2 C: 0.2 Fe: Balance</td>
</tr>
<tr>
<td>Precipitation Hardening</td>
<td>Typically EN1.4542/AISI 630 Cr: 17 Ni: 4 Cu:4 Fe: Balance</td>
</tr>
</tbody>
</table>

Common Properties:
- Fair to good corrosion resistance, increases with alloy content
- **High strength** obtained by heat treatment (not by cold work). Limited elongation.
- Not suitable for use at very low temperatures
- Not suitable for forming, often processed by machining
- Can be welded (TIG, MIG), but require usually post-weld heat treatment

Are used as engineering steels with corrosion resistance
Duplex (Austenitic-Ferritic)

Sub-groups:
- Cr-Ni: Typically EN1.4362, Cr: 23, Ni: 4, Fe: Balance
- Cr-Ni-Mo: Typically EN1.4462, Cr: 22, Ni: 5, Mo: 3, Fe: Balance

Common Properties:
- Excellent corrosion resistance, increases with alloy content
- Insensitive to Stress Corrosion Cracking
- High strength, good ductility
- Strength can be increased by cold working (but not by heat treatment)
- Good cold and hot forming properties (ductility, elongation)
- Weldable (TIG, MIG)

Offer the best combination of corrosion resistance and mechanical properties

Colour code:
- Corrosion resistance
- Mechanical properties
- Fabrication
## Physical properties

<table>
<thead>
<tr>
<th>Materials</th>
<th>Modulus of Elasticity Gpa</th>
<th>Thermal Expansion Coefficient $10^{-6} \cdot \text{K}^{-1}$</th>
<th>Thermal Conductivity $W \cdot \text{m}^{-1} \cdot \text{K}^{-1}$</th>
<th>Ferro-Magnetism</th>
<th>Density Kg/dm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr-Ni Austenitics</td>
<td>210</td>
<td>18</td>
<td>15</td>
<td>No</td>
<td>7.8</td>
</tr>
<tr>
<td>Cr-Mn Austenitics</td>
<td>210</td>
<td>17</td>
<td>15</td>
<td>No</td>
<td>7.8</td>
</tr>
<tr>
<td>Cr Ferritics</td>
<td>220</td>
<td>11</td>
<td>23</td>
<td>Yes</td>
<td>7.7</td>
</tr>
<tr>
<td>Cr-Ni (Mo)-N Duplex</td>
<td>210</td>
<td>14</td>
<td>15</td>
<td>Intermediate</td>
<td>7.8</td>
</tr>
<tr>
<td>Cr-C Martensitics</td>
<td>215</td>
<td>11</td>
<td>30</td>
<td>Yes</td>
<td>7.7</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>210</td>
<td>12</td>
<td>18</td>
<td>Yes</td>
<td>7.8</td>
</tr>
<tr>
<td>Copper</td>
<td>135</td>
<td>17</td>
<td>380</td>
<td>No</td>
<td>8.3</td>
</tr>
<tr>
<td>Aluminum</td>
<td>70</td>
<td>22</td>
<td>230</td>
<td>No</td>
<td>2.7</td>
</tr>
<tr>
<td>Glass</td>
<td>65</td>
<td>9</td>
<td>1.7</td>
<td>No</td>
<td>2.5</td>
</tr>
<tr>
<td>Concrete</td>
<td>48</td>
<td>10</td>
<td>1</td>
<td>No</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Standards on Stainless Steels

Main World Standards:

<table>
<thead>
<tr>
<th>ISO</th>
<th>EN</th>
<th>ASTM/AISI</th>
<th>UNS</th>
<th>JIS</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="ISO.png" alt="ISO" /></td>
<td><img src="EN.png" alt="EN" /></td>
<td><img src="ASTM.png" alt="ASTM/AISI" /></td>
<td><img src="UNS.png" alt="UNS" /></td>
<td><img src="JIS.png" alt="JIS" /></td>
</tr>
</tbody>
</table>

Notes:
Most countries refer to the above standards, which are widely accepted. A lot of the grades are very similar in all of the above standards.

List of the American Standards: ref 11
List of European Standards: ref 12

Correspondance tables are available: refs 13 - 15
### Main grades in Architecture Building and Construction: EN 10088-4 (for sheet/plate/strip) \(^{16, 17}\)

<table>
<thead>
<tr>
<th>Grade</th>
<th>ASTM UNS</th>
<th>C Wt%</th>
<th>Cr Wt%</th>
<th>Ni Wt%</th>
<th>Mo Wt%</th>
<th>Other Wt%</th>
<th>Typical use (^{3,4})</th>
</tr>
</thead>
<tbody>
<tr>
<td>4003</td>
<td>S40977</td>
<td>0,02</td>
<td>11,5</td>
<td>0,5</td>
<td>-</td>
<td>-</td>
<td>heated and unheated interiors</td>
</tr>
<tr>
<td>4016</td>
<td>430</td>
<td>0,04</td>
<td>16,5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>decorative interior cladding</td>
</tr>
<tr>
<td>4509</td>
<td>S43932</td>
<td>0,02</td>
<td>18</td>
<td>-</td>
<td>-</td>
<td>Nb Ti</td>
<td>inland roofing and rainwater goods - often Tin-coated for patina</td>
</tr>
<tr>
<td>4510</td>
<td>439</td>
<td>0,02</td>
<td>17</td>
<td>-</td>
<td>-</td>
<td>Ti</td>
<td></td>
</tr>
<tr>
<td>4521</td>
<td>444</td>
<td>0,02</td>
<td>17,8</td>
<td>-</td>
<td>2,1</td>
<td>Ti</td>
<td>domestic plumbing market</td>
</tr>
<tr>
<td>4301</td>
<td>304</td>
<td>0,04</td>
<td>18,1</td>
<td>8,1</td>
<td>-</td>
<td>-</td>
<td>building interiors and exteriors in normal industrial atmospheres away from the coast</td>
</tr>
<tr>
<td>4307</td>
<td>304L</td>
<td>0,02</td>
<td>18,2</td>
<td>8,1</td>
<td>10,1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4306</td>
<td>304L</td>
<td>0,02</td>
<td>18,3</td>
<td>10,9</td>
<td>2,1</td>
<td>Ti</td>
<td></td>
</tr>
<tr>
<td>4401</td>
<td>316</td>
<td>0,04</td>
<td>17,2</td>
<td>10,1</td>
<td>2,1</td>
<td>Ti</td>
<td>permanently wet applications, locations in a coastal atmosphere, polluted industrial atmospheres or near roads where de-icing salts can be an issue</td>
</tr>
<tr>
<td>4404</td>
<td>316L</td>
<td>0,02</td>
<td>17,2</td>
<td>10,1</td>
<td>2,1</td>
<td>Ti</td>
<td></td>
</tr>
<tr>
<td>4571</td>
<td>316Ti</td>
<td>0,04</td>
<td>16,8</td>
<td>10,9</td>
<td>2,1</td>
<td>Ti</td>
<td></td>
</tr>
<tr>
<td>4529</td>
<td>N08926</td>
<td>0,01</td>
<td>20,5</td>
<td>6,5</td>
<td>N, Cu</td>
<td>N, Cu</td>
<td>road tunnels and indoor swimming pools</td>
</tr>
<tr>
<td>4547</td>
<td>S31254</td>
<td>0,01</td>
<td>20,0</td>
<td>6,1</td>
<td>N, Cu</td>
<td>N, Cu</td>
<td></td>
</tr>
</tbody>
</table>

ABC = Architecture, Building and Construction
Main grades in Architecture Building and Construction: EN 10088-5(for bars/wires/sections)\textsuperscript{18}

<table>
<thead>
<tr>
<th>Grade</th>
<th>ASTM UNS</th>
<th>C Wt%</th>
<th>Cr Wt%</th>
<th>Ni Wt%</th>
<th>Mo Wt%</th>
<th>Other Wt%</th>
<th>Typical use \textsuperscript{6}</th>
</tr>
</thead>
<tbody>
<tr>
<td>4003</td>
<td>S40977</td>
<td>0,02</td>
<td>11,5</td>
<td>0,5</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4016</td>
<td>430</td>
<td>0,04</td>
<td>16,5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Slate hooks</td>
</tr>
<tr>
<td>4542</td>
<td>630</td>
<td>0,04</td>
<td>16,0</td>
<td>4,0</td>
<td>Cu,Nb</td>
<td>Tie bars</td>
<td></td>
</tr>
<tr>
<td>4301</td>
<td>304</td>
<td>0,04</td>
<td>18,1</td>
<td>8,1</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4307</td>
<td>304L</td>
<td>0,02</td>
<td>18,1</td>
<td>8,1</td>
<td>-</td>
<td>N</td>
<td>Rebar</td>
</tr>
<tr>
<td>4311</td>
<td>304N</td>
<td>0,02</td>
<td>18,1</td>
<td>8,6</td>
<td>-</td>
<td>Cu</td>
<td>A2 fasteners</td>
</tr>
<tr>
<td>4567</td>
<td>304Cu</td>
<td>0,02</td>
<td>17,1</td>
<td>8,6</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4401</td>
<td>316</td>
<td>0,05</td>
<td>16,6</td>
<td>10,1</td>
<td>2,1</td>
<td>-</td>
<td>Building interiors and exteriors in normal industrial atmospheres away from the coast, Rebar</td>
</tr>
<tr>
<td>4404</td>
<td>316L « 316LN »</td>
<td>0,02</td>
<td>16,6</td>
<td>10,1</td>
<td>2,1</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>4429</td>
<td>« 926 » S31254</td>
<td>0,01</td>
<td>20,5</td>
<td>24,8</td>
<td>6,5</td>
<td>N, Cu</td>
<td>Road tunnels and indoor swimming pools</td>
</tr>
<tr>
<td>4529</td>
<td>« 926 » S31254</td>
<td>0,01</td>
<td>20,0</td>
<td>18,0</td>
<td>6,1</td>
<td>N, Cu</td>
<td>Rebar and mechanical components</td>
</tr>
<tr>
<td>4547</td>
<td>S32304</td>
<td>0,02</td>
<td>22,5</td>
<td>3,6</td>
<td>0,3</td>
<td>N, Cu</td>
<td>Rebar and mechanical components</td>
</tr>
<tr>
<td>4362</td>
<td>S32205</td>
<td>0,02</td>
<td>21,5</td>
<td>4,6</td>
<td>2,8</td>
<td>N</td>
<td>Rebar and mechanical components</td>
</tr>
</tbody>
</table>

\textsuperscript{6} Rebar
Breakdown of the stainless steel production worldwide by family
High Ni prices favour the replacement of popular CrNi grades by Cr-Mn or Cr Grades. Duplex grades marginal today, are expected to grow in the future.
What are stainless steels?

Stainless steel meltshop production in kt (metric)

Others: Brazil, Russia, S Korea Indonesia

UPDATED 2018!
Apparent stainless use by region

Western Europe  Central/Eastern Europe  Americas  Asia excluding China  China  Others
References (1/2)

6. The ferritic solution http://worldstainless.org/publications/brochures_and_posters
References (2/2)


19. ISSF publication « Stainless Steel in Figures »: http://www.worldstainless.org/statistics/publications_and_papers
Thank you!

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6